

# Middlesex University Research Repository

An open access repository of

Middlesex University research

<http://eprints.mdx.ac.uk>

Jones, Alexander (2019) Temporal expectancies and rhythmic cueing in touch: the influence of spatial attention. *Cognition*, 182 . pp. 140-150. ISSN 0010-0277 [Article]  
(doi:10.1016/j.cognition.2018.09.011)

Final accepted version (with author's formatting)

This version is available at: <https://eprints.mdx.ac.uk/25211/>

## Copyright:

Middlesex University Research Repository makes the University's research available electronically.

Copyright and moral rights to this work are retained by the author and/or other copyright owners unless otherwise stated. The work is supplied on the understanding that any use for commercial gain is strictly forbidden. A copy may be downloaded for personal, non-commercial, research or study without prior permission and without charge.

Works, including theses and research projects, may not be reproduced in any format or medium, or extensive quotations taken from them, or their content changed in any way, without first obtaining permission in writing from the copyright holder(s). They may not be sold or exploited commercially in any format or medium without the prior written permission of the copyright holder(s).

Full bibliographic details must be given when referring to, or quoting from full items including the author's name, the title of the work, publication details where relevant (place, publisher, date), pagination, and for theses or dissertations the awarding institution, the degree type awarded, and the date of the award.

If you believe that any material held in the repository infringes copyright law, please contact the Repository Team at Middlesex University via the following email address:

[eprints@mdx.ac.uk](mailto:eprints@mdx.ac.uk)

The item will be removed from the repository while any claim is being investigated.

See also repository copyright: re-use policy: <http://eprints.mdx.ac.uk/policies.html#copy>

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Title page:

Running head: Temporal and spatial attention in touch

**Title:**

**Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention**

Alexander Jones, PhD.

**Corresponding author present address:**

Alexander Jones  
Department of Psychology  
School of Science & Technology  
Middlesex University  
London NW4 4BT  
United Kingdom

Tel: +44 (0)208 411 6328

Email: [a.j.jones@mdx.ac.uk](mailto:a.j.jones@mdx.ac.uk)

[www.jones-silas-lab.com](http://www.jones-silas-lab.com)

Declarations of interest: none

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

## **Abstract**

Attention resources can be allocated in both space and time. Exogenous temporal attention can be driven by rhythmic events in our environment which automatically entrain periods of attention. Temporal expectancies can also be generated by the elapse of time, leading to foreperiod effects (the longer between a cue and imperative target, the faster the response). This study investigates temporal attention in touch and the influence of spatial orienting. In experiment 1, participants used bilateral tactile cues to orient endogenous spatial attention to the left or right hand where a unilateral tactile target was presented. This facilitated response times for attended over unattended targets. In experiment 2, the cue was unilateral and non-predictive of the target location resulting in inhibition of return. Importantly, the cue was rhythmic and targets were presented early, in synchrony or late in relation to the rhythmic cue. A foreperiod effect was observed in experiment 1 that was independent from any spatial attention effects. In experiment 2, in synchrony were slower compared to out of synchrony targets but only for cued and not uncued targets, suggesting the rhythm generates periods of exogenous inhibition. Taken together, temporal and spatial attention interact in touch, but only when both types of attention are exogenous. If the task requires endogenous spatial orienting, space and time are independent.

**Keywords:** Foreperiod, Hazard function, Inhibition of return (IOR), Somatosensory, Temporal attention

## 1. Introduction

Our sensory system is constantly exposed to vast amounts of information. To efficiently deal with this information, interact with the world and guide our behaviour, we need to select, predict and prioritize certain events and stimuli over others. This is collectively known as attention and can be directed in both space and time (Coull & Nobre, 1998). Spatial attention typically distinguishes between endogenous and exogenous orienting, the former being voluntary and the latter stimulus driven (Corbetta & Shulman, 2002; Posner, 1980). Endogenous attention to a spatial location has been shown to enhance perceptual processing (e.g., Mangun & Hillyard, 1990; Yeshurun & Carrasco, 1998) as well as facilitate behaviour for stimuli at attended compared to unattended locations (see Carrasco, 2014 for a review).

Interactions with events in our environment rely not only on *where* something happens but also on *when* an event occurs. The general terms used to describe expectations and associations of events based on timing is known as temporal attention. There are several different types of temporal structures which can guide temporal attention such as associations, hazard rates, sequences and rhythms (see Nobre and van Ede, 2018, for a recent review of temporal attention). Similar to spatial attention, these temporal structures can be stimulus driven and automatic (exogenous temporal attention) or under voluntary control (endogenous temporal attention). Endogenous temporal attention has been investigated using temporal cueing tasks where temporal associations between stimuli are formed. In a Posner like cue-target paradigm, a symbolic temporal cue can be used to direct attention to a moment in time in anticipation of an upcoming target. To note is that the stimuli used in such paradigms are typically visual or auditory and little is known about the effects in touch; the modality of interest in the present study. Endogenous temporal attention has been shown to facilitate response times (RTs) (Griffin, Miniussi, & Nobre, 2001; Lange and Röder, 2006; Pomper, Keil, Foxe, & Senkowski, 2015), perceptual discrimination (Correa, Lupiáñez, & Tudela, 2005; Rohenkohl et al., 2014) and enhance neural processing at attended over unattended times (Buhusi & Meck, 2005 Correa, Lupianez, Madrid, & Tudela, 2006; Rohenkohl & Nobre, 2011; Zanto et al., 2011). Temporal attention can also be exogenous and driven by stimuli in our environment such as a rhythm (Rohenkohl, Coull, & Nobre, 2011; see Klein and Lawrence, 2012; and Lawrence & Klein 2013, for a review and framework for the allocation of temporal and spatial attention). Even in the absence of external stimuli and associations, temporal expectancies can be formed by the passage of time itself. The likelihood of an event occurring may vary over time. This automatic temporal expectation of elapsed time is continuously updated and has been used to explain the foreperiod effect whereby RTs are typically faster for longer compared to shorter foreperiods (Karlin, 1959;

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Niemi & Naatanen, 1981; Nobre et al., 2007). In other words, the longer between a cue and imperative target, the faster you respond. This increase in expectation has been expressed as the 'hazard function' which is the likelihood of an imperative event increases with time, if it has not yet occurred (Janssen & Shadlen, 2005; Luce, 1986; Nobre et al., 2007). For example, the likelihood that the traffic light will turn green increases the longer you wait. The foreperiod effect is automatic but can be influenced and eliminated if the cue-target interval is fixed rather than variable (Coull, Cotti, & Vidal, 2016; Nobre & Rohenkohl, 2014). That is, if a cue is informative of when an upcoming target is likely to appear and thus endogenous temporal attention is allocated to a moment in time, the foreperiod effect is reduced or eliminated (Coull et al., 2016). The effects of endogenous temporal attention have not only been explored using a single symbolic cue, but also using rhythms. Rhythms themselves can be explicitly attended to and used as an endogenous temporal cue to speed up target detection (Doherty, Rao, Mesulam, & Nobre, 2005), but rhythms can also elicit exogenous temporal attention effects without the need to attend to the rhythmic events (Rohenkohl et al., 2011; Ball et al., 2018). In other words, rhythms can independently affect and facilitate performance regardless if they are relevant to the task or predictive of a target event (Breska & Deouell, 2014; Sanabria et al., 2011).

The effects of rhythmic structures have been explained through the dynamic attending theory (DAT) which proposes that rhythms entrain periodic fluctuations of attention which modulate the gain of sensory input (Large & Jones, 1999). Jones, Moynihan, Mackenzie, & Puente (2002) conducted a seminal study providing empirical support for the DAT. Participants were asked to judge if two tones, one at the start and one at the end of the trial, were of the same pitch. Sandwiched between the first (standard) and last (comparison) tone was a stream of regularly presented tones forming a rhythm. Crucially, the comparison tone at the end of the trial could be presented in synchrony with the rhythm or slightly early or late. Jones and colleagues found that the pitch judgment accuracy followed an inverted U-shaped pattern whereby accuracy was best when comparison tones were presented on the beat and tailing off if appeared early or late. It is important to note that the rhythm was not task-relevant and did not explicitly help with performing the pitch judgement task. Presenting stimuli in synchrony with a rhythm has been shown to improve choice RTs (Martin et al., 2005), detection thresholds (Herrmann, Henry, Haegens, & Obleser, 2016; Lawrance, Harper, Cooke, & Schnupp, 2014) and perceptual discrimination (Rohenkohl, Cravo, & Wyart, 2012).

In line with the DAT theory, research has observed that intrinsic neural oscillations can entrain to external rhythms by aligning the firing pattern of neurons with rhythms in our environment (Arnal &

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Giraud, 2012; Lakatos, Karmos, Mehta, Ulbert, & Schroeder, 2008; for reviews see Calderone, Lakatos, Butler, & Castellanos, 2014; Henry & Herrmann, 2014). In other words, groups of neurons start to fire in synchrony with external rhythms. By locking onto these rhythms, the brain automatically creates time points where stimuli is thought to be better processed. Perception of near threshold stimuli has been shown to be influenced, depending on where in the phase of the oscillation the stimuli are presented (Busch, Dubois, & VanRullen, 2009; Henry & Obleser, 2012; see Van Rullen, 2016; Haegens and Golumbic, 2018, for recent reviews). Many examples of rhythmic patterns in the environment, such as walking, running, speech, listening to or playing music, involve motor and somatosensory input. The motor system is imperative in generating temporal predictions which shape perception (Grahn & Rowe, 2013; Morillon, Hackett, Kajikawa, & Schroeder, 2015; Schubotz, 2007) and the somatosensory system is closely linked to the motor system (van Ede, Winner, & Maris, 2015; Zagha, Casale, Sachdev, McGinley, & McCormick, 2013) and actively engaged in synchronized rhythmic movements (Todd & Lee, 2015). Yet, little is known about how we process rhythms in touch (although see Dockstader, Cheyne, & Tannock, 2010; Giabbiconi, Dancer, Zopf, Gruber, & Müller, 2004) and how spatial orienting of attention influences the effects of rhythmic input, and vice versa. The current research addresses this.

Spatial and temporal attention have been independently explored in the tactile domain, and in a similar manner to visual spatial attention research, variations of the Posner cue-target paradigm have been used (Posner, 1980). In an endogenous version of this paradigm a cue, for example a visual arrow or informative vibration, indicates to which hand an upcoming tactile target (e.g. a tap to the finger) will appear (Haegens, Handel, & Jensen, 2011). Endogenously attending to a location on the body has been shown to facilitate RTs (Jones & Forster, 2014; Spence & Gallace, 2007) and enhances early ERP components (e.g. P100) linked to somatosensory analysis (Sambo & Forster, 2011). In an exogenous version, the cue is non-informative (e.g., a tap to the left or right hand) and a target is presented to the same or opposite hand. This typically leads to inhibition of return (IOR; Klein, 2000) with slower RTs for cued compared to uncued targets and has been observed in both detection (Jones & Forster, 2012; Lloyd et al., 1999) and discrimination tasks (Brown et al., 2010). When endogenous and exogenous spatial attention have been contrasted, independent RT effects have been observed suggesting these are separate mechanisms, at least under low task demands (Jones & Forster, 2013, 2014; see also Berger, Henik, & Rafal, 2005 for similar results in visual orienting). The effects of tactile temporal attention have been less explored but with a few exceptions. van Ede, de Lange, Jensen, & Maris (2011) presented participants with a spatially informative auditory cue indicating to which hand an upcoming tactile target would be presented.

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

The target was then presented after one of three different time intervals. van Ede and colleagues observed faster RTs for longer intervals between cue and target, consistent with the hazard function (Janssen & Shadlen, 2005; Luce, 1986).

The aim of the current study is to investigate how the effects of exogenous temporal attention in touch are affected by endogenous and exogenous spatial attention. In this article, the term temporal attention will refer to predictive temporal structures which are used to prioritize and select relevant items to guide behaviour (Nobre and van Ede, 2018). Moreover, and in line with Nobre and van Ede's (2018) definition, temporal expectation refers to the neural or cognitive state of predicted timing of an event and with no implications concerning volition, awareness or conscious deliberation. Endogenous temporal attention in the present article refers to voluntarily anticipating moments in time (the present study did not explicitly manipulate endogenous temporal attention). Exogenous temporal attention includes both the effects of the rhythmic temporal structure, which can automatically generate predictions about the timing of an event, and also foreperiod effects which are automatically driven by the passage of time. The current study, comprised of two independent experiments, uses a novel version of a Posner cue-target paradigm, manipulating spatial and temporal attention in a single trial. Instead of the cue being for example, an arrow or single tap, the cue itself forms a rhythm of tactile events. In the endogenous spatial attention tasks (experiment 1), the rhythmic cue is bilateral and informs whether to attend to the left or right hand. In the exogenous task (experiment 2), the rhythmic cue is unilateral and non-informative as to which hand the upcoming target will appear. A target then appears early, in synchrony or late in relation to the rhythmic cue. Importantly, whether the target appears in synchrony with the rhythm is not task-relevant. The first objective was to investigate exogenous temporal attention in touch which could lead to two possible outcomes, both of which might be observed. First, rhythmic tactile stimuli are automatically entrained and observed effects follow the DAT theory with faster RTs to in synchrony targets compared to early and late targets. Second, RTs are influenced by the probability of target events over time and follow the foreperiod effect with faster RTs for late, compared to in synchrony and then slowest RTs for early targets. To gain further insight into these two possible outcomes the target could appear after either four or five rhythmic stimuli, providing six possible target locations. The second objective was to investigate how endogenous and exogenous spatial attention affect exogenous temporal attention. To foreshadow the results, exogenous temporal attention effects were independent from endogenous spatial orienting but interacted with exogenous spatial attention.

## **2. Experiment 1 - Endogenous spatial and exogenous temporal attention**

Cite as:  
Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

## **2.1 Methods**

Experiment 1 is made up of two separate tasks. In both tasks, a rhythmic tactile cue was presented to the hands. In one task participants had to detect a tactile target (detection task) and in a second task discriminate between two taps (discrimination task). The term detection task here refers to when the target was a single tap, and the participant did not have to discriminate between different types of targets, similar to comparable research using a cue-target paradigm (see Chica et al., 2014 for a review on the spatial orienting paradigm). However, it should be noted that the participant still had to “discriminate” between left and right targets (see Tamè & Holmes, 2016 for a detailed discussion on tactile detection and discrimination tasks). The two tasks were contained in two separate experiments and no participant took part in both tasks. The rationale for using both a detection and discrimination task was because detection tasks have been proposed to be less sensitive to shifts of endogenous tactile spatial attention whilst discrimination tasks require more in-depth target processing leading to clearer cueing effects (Posner, 1978; Spence, Pavani, & Driver, 2000).

### **2.1.1 Participants**

All participants took part voluntarily and some also received course-credits in return for participating. All participants provided written informed consent and the study was approved by the Psychology Department Ethics committee, Middlesex University.

#### *Detection task*

Forty participants took part in the detection task, and 31 were included in the analysis. Of these, 19 were females and 12 were males with an average age of 22.2 years ( $SD = 2.4$ ). Nine participants were excluded due to not following task instructions and responding to too many catch trials (more than 50%) and/or missing too many targets (above 10%).

#### *Discrimination task*

Forty participants took part in the study and 28 were included in the analysis (20 females and 8 males, average age 22.3 years;  $SD = 2.3$ ). Twelve were excluded due to not following task instructions and responding to too many catch trials (above 50%) and/or making too many discrimination errors or missing targets (above 10%).

### **2.1.2 Materials and apparatus**



Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Tactile stimuli were presented using tactors connected to a TactAmp (Dancer Design, Ltd). The tactors (Dancer Design, Ltd) are miniature electromagnetic solenoid-type stimulators, 18mm diameter, which drive a flat probe magnet (approx. 2mm in diameter) up and down creating the sensation of a tap. The tactors were mounted 60 cm apart. Participants rested their index and middle finger fingertips on the tactors with their hands palm down on a foam-covered table. Headphones played white noise (at a comfortable listening level) to mask any sounds made by the tactors. RTs were recorded using a voicekey connected to the TactAmp. A voicekey was selected as the response option instead of for example a foot response, to avoid unwanted stimulus-response compatibility effects (Kornblum, Hasbroucq, & Osman, 1990). Moreover, the distance between the stimulated hand and a left-right foot response has been shown to influence attention effects (Lloyd et al., 2010) and a voicekey has been proposed as a preferable response mode (Le Bigot & Grosjean, 2016). However, occasionally the voicekey did not pick up a response, which could be due to the battery in the voicekey being low, or the participant responding too quietly. This technical error may partly account for the large loss of participants in section 2.1.1. E-Prime v.2 (Psychology Software Tools) was used for stimulus presentation and to record behavioural responses. The voicekey onset is recorded as an event in E-Prime and the RT is calculated as the duration of the response period which is the time between target offset and voicekey onset. The TactAmp was connected to the PCs parallel port and therefore both output signal (to the tactors) and input signal (voicekey RTs) were driven by the same apparatus and port, which is considered beneficial in terms of timing precision. The timing precision of stimulus presentation was additionally verified by sending an identical visual stimuli to a LED connected to the TactAmp (LEDs and tactors are both driven by the same parallel port and same code in E-Prime, only different pins). A photodiode, connected to an EEG amplifier (ActiveTwo system, BioSemi, Amsterdam) recorded the visual evoked potential. The precision of the timing was within 4 ms. A black fixation-cross was displayed centrally on a 17" PC monitor approximately one meter in front of the participant throughout the experiment. A towel was used to cover participants' hands throughout the experiment to avoid visual input of the stimulated site (Sambo, Gillmeister, & Forster, 2009).

#### **2.1.2.1 Supplementary materials**

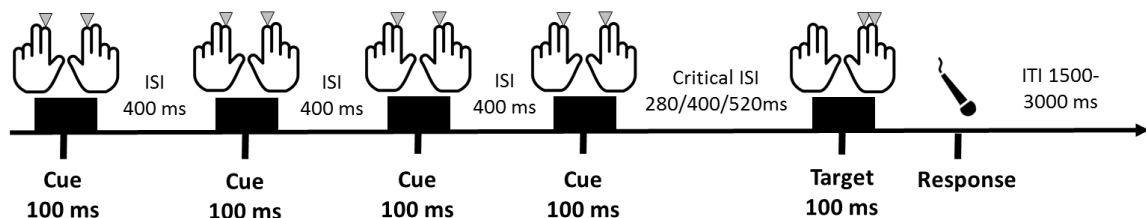
Data from this study are publicly available here: <https://osf.io/v7xbv/>

#### **2.1.3 Design and Procedure**

Each trial started with a rhythmic cue presented to participants' middle or index fingers of both hands (see Figure 1 for a schematic view of events in a trial). The cue was a repetition of four or five

Cite as:  
 Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

taps, each being 100 milliseconds (ms) in duration. The inter-stimulus interval (ISI) between the taps was 400 ms and therefore, together with the cue, the stimulus onset asynchrony (SOA) was 500 ms generating a 2 Hz tactile rhythm. After the presentation of four or five taps to both hands, the tactile target appeared to one hand only and participants made a response. Half of the trials included five taps before target presentation and half four taps (the trial order was randomized). For half of the participants, cues delivered to the index fingers indicated that the target would most likely (75%) appear to their right hand, whereas cues delivered to the middle fingers indicated that the target would likely appear to the left hand. For the other half, this association was reversed (i.e. middle finger taps meant attend right). In the detection task, the target was a 100 ms single 'tap' to both the middle and index fingers of one hand. Participants were instructed to use the spatial cues to speed up their RTs, and say 'pa' as soon as they detected the target at either right or left hand. In the discrimination task, the target was either a single or double tap. The single tap target was identical to the target used in the detection task. The double tap target consisted of two 40 ms taps with an ISI of 20 ms, which is equal to a total of 100 ms target duration. In the discrimination task participants responded 'one' for the single tap target and 'two' for the double tap target. The experimenter recorded/labelled the response (one or two) in the adjacent room on a keyboard. Exogenous temporal attention was manipulated by varying the foreperiod and presenting the target either in or out of synchrony with the rhythm generated by the cue, and the critical ISIs preceding the targets were 280 ms (early), 400 ms (sync), and 520 ms (late). Importantly, the temporal manipulation was not task-relevant. The critical ISIs were selected to be comparable with a similar study using visual and auditory stimuli (Jones, 2015) and moreover, the out of synchrony ISI was selected so the target did not fall on a 2 Hz harmonic frequency (4 Hz, 6 Hz, 8 Hz etc.). There was a random inter-trial interval (ITI) of between 1500 – 3000 ms, and if no response was recorded within 1600 ms it was counted as a miss and the trial moved onto the ITI.



**Figure 1.** Schematic view of events in a trial in the endogenous tasks, experiment 1. The cue was a series of 100 ms taps delivered to the index fingers (indicated by the grey triangle) or middle fingers of both hands. Bilateral stimulation of the index fingers served as a cue to attend to the left, and stimulation of the middle

Cite as:

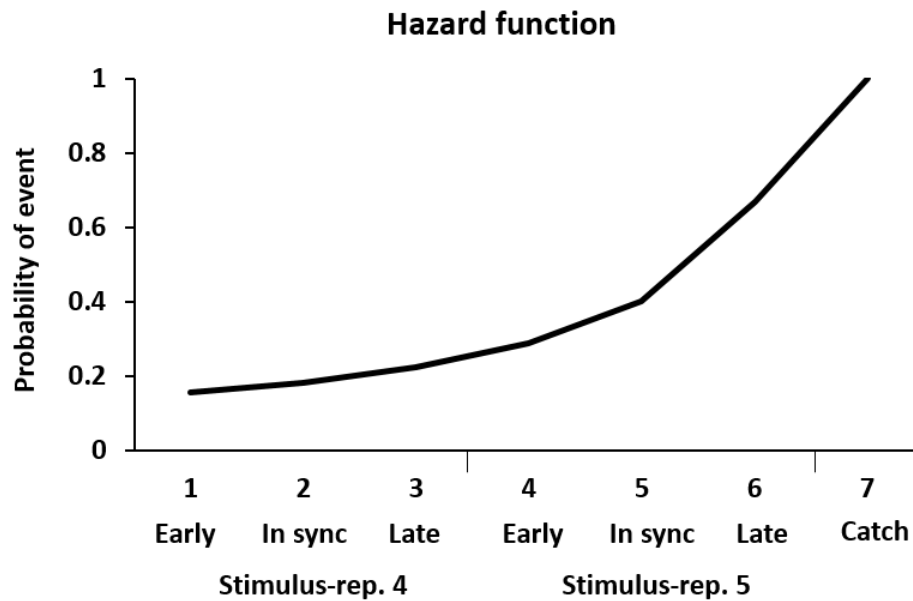
Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

fingers cued attention to the right (counterbalanced across participants). There were either four (as pictured above) or five bilateral taps in a trial, generating a 2 Hz rhythm. The target, presented to both index and middle fingers of one hand, was either presented slightly early, in synchrony or late in relation to the rhythm (critical ISI 280, 400 or 520 ms respectively). In the detection task, the target was a single tap and discrimination task a single or double tap. The participants responded by saying “pa” into a microphone in the detection task and either “one” or “two” in the discrimination task. In both tasks, targets were 75% likely to appear at the attended hand and 25% at the unattended hand. The schematic representation in the figure shows an unattended trial with the cue to the index fingers instructing participants to attend to the left, but the target appears to the right hand.

The experiment took between 45 – 60 minutes to complete. Instructions were given both as text and verbally and participants also completed two short practice blocks. Between the experimental blocks, participants were provided with feedback on their performance, with their average RTs for the attended and unattended trials displayed on the monitor. Participants were allowed short breaks between the blocks.

Both the detection and discrimination tasks included 416 trials each, presented in eight blocks of 52 trials. Out of these, targets were presented to the attended hand on 288 trials (75%) and 96 trials included unattended target (25%). Targets were presented either after four or five stimulus-repetitions (192 trials each), and either early, in synchrony or late in relation to the rhythmic cue. There were 64 trials for each of the six conditions (e.g. early and four stimulus-repetitions), and an additional 32 trials were catch trials where no target was presented. The trials were presented in a random order.

The probability of the early, in synchrony, and late stimuli occurring was .308 each and the probability of a catch trial occurring was .077. The hazard rate function (Luce, 1986) is the probability that an event will occur at a particular time, divided by the probability that it has not yet occurred, prior to each of the seven possible events. The seven possible events are the six possible timings the target could be presented at. If it was not presented at either one of the six time points, then the trial was a catch trial. The probability that the event (the target) would occur was; four stimulus-rep./early  $p=.15$ , four stimulus-rep./in sync.  $p=.18$ , four stimulus-rep./late  $p=.22$ , five stimulus-rep./early  $p=.29$ , five stimulus-rep./in sync.  $p=.4$ , five stimulus-rep./late  $p=.67$ , and catch trial  $p=1.0$  (see Figure 2).



**Figure 2.** The hazard function, the probability of an event occurring if it has not yet occurred, plotted for each of the seven possible target events.

#### *Data analysis*

Using Microsoft Excel 2013, RTs were trimmed to exclude outliers. Specifically, an average was first computed for each participant (excluding RT=0 ms, which were missed targets). Then responses faster than 100 ms were labelled false alarms<sup>1</sup> and responses exceeding 2.5 standard deviations above the individual participants average RT, across all conditions, were excluded from further analysis (see e.g., Gabay & Henik, 2008; Mora-Cortes, Ridderinkhof, & Cohen, 2017; Noel, Pfeiffer, & Blanke, 2015, for similar response trimming criterion). An average was then computed for each condition and imported to IBM SPSS Statistics for Windows v. 21 for statistical analysis. Where the assumption of sphericity has been violated, Greenhouse-Geisser adjusted degrees of freedom and probability levels are reported. Data were submitted to a 2x2x2x3 mixed design ANOVA with the between-subjects' factor being Task (detection, discrimination), and within-subject factors were

<sup>1</sup>There is little consensus in the literature of a criterion to be used for excluding false alarms when using a voicekey. For example, in a study investigating the bias in voicekey responses, concluding that the RT is dependent upon the leading phoneme of the vocal response, Kessler et al (2002) used a 100 ms criterion to exclude false alarms. In a large scale study (The English Lexicon Project, Balota et al., 2007), analysing over 3 million voicekey responses to visual stimuli (lexical decision and speed naming task) a 200 ms criterion was selected. However, a standard threshold is further complicated with responses to tactile stimuli being on average 34 % faster than visual stimuli (Ng & Chan, 2012). The 100 ms criterion for false alarms in the present study is calculated from the offset of the target, which equates to 200 ms from target onset. A 200 ms cut-off for false alarms from target onset is comparable other studies using a voicekey and tactile stimuli (e.g., Katus and Müller, 2016).

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Spatial attention (attended, unattended), Stimulus-repetition (4, 5 taps), and Foreperiod (early, in synchrony, and late). The dependent variable was RTs.

To determine whether non-significant effects support the null hypothesis or the data are insensitive, Bayes Factor analysis (Dienes, 2014) was conducted using JASP (Version 0.8.6)[Computer software]. The analysis procedure was based on Wagenmakers et al. (2017) where  $BF_{10}$  was computed and a value less than 1/3 is taken as support for the null hypothesis.

## 2.2. Results and discussion

### *Accuracy*

In the detection task participants missed on average 1.7% (SD=2.0) of targets with no individual missing more than 7.3% of targets. The participants responded on average to 3.9% (SD=4.8) of catch trials. In the discrimination task participants on average missed 1.3% (SD=2.0) of targets, responded to 4.6% (SD=9.0) of catch trials and made 2.5% (SD=2.4) of target discrimination task errors (reporting one instead of two taps or vice versa). There was no significant difference between target discrimination errors between attended (M=2.5%, SD=2.1) and unattended targets (M=2.4%, SD=2.7) ( $t(247)=0.34$ ,  $p=.74$ ) (see Appendix A for further breakdown of discrimination errors).

### *Response times*

There was a main effect of Task ( $F(1,57)=14.27$ ,  $p<.001$ ,  $\eta^2_p=.20$ ) with overall faster responses in the detection (M=437.76 ms, SEM=34.44) compared to the discrimination task (M=626.61 ms, SEM=36.24). No other effects including the factor Task<sup>2</sup> were significant. There was a main effect of Spatial attention ( $F(1,57)=51.67$ ,  $p<.001$ ,  $\eta^2_p=.48$ ) with RTs being faster for attended (M=507.74 ms, SEM=24.07) compared to unattended targets (M=556.64 ms, SEM=26.33) (see Figure 3, top). There was a main effect of Foreperiod ( $F(2,114)=6.63$ ,  $p=.002$ ,  $\eta^2_p=.10$ ) and trend analysis showed this effect was linear ( $F(1,57)=8.68$ ,  $p=.005$ ,  $\eta^2_p=.13$ ) and not quadratic ( $p=.085$ ,  $\eta^2_p=.05$ ).

There was a Foreperiod\*Stimulus-repetition interaction ( $F(2,114)=18.29$ ,  $p<.001$ ,  $\eta^2_p=.24$ ) which was followed up by separate analysis of Foreperiod for 4 and 5 Stimulus-repetitions (see Table 1 for a breakdown of RTs).

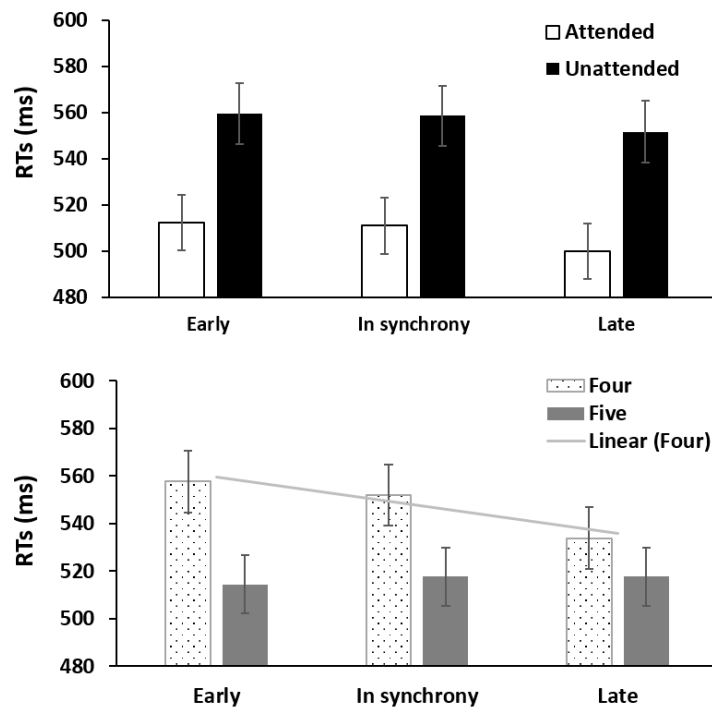
---

<sup>2</sup> Non-significant effects including Task: Task\*Cue-repetition ( $p=.057$ ,  $\eta^2_p=.06$ ,  $BF_{10}=1.13$ ); Task\*Foreperiod ( $p=.21$ ,  $\eta^2_p=.03$ ,  $BF_{10}=0.05$ ); Task\*Spatial attention ( $p=.94$ ,  $\eta^2_p<.01$ ,  $BF_{10}=0.12$ ); Task\*Spatial attention\*Foreperiod ( $p=.17$ ,  $\eta^2_p=.03$ ,  $BF_{10}=0.12$ ); Task\*Spatial attention\*Cue-repetition ( $p=.60$ ,  $\eta^2_p<.01$ ,  $BF_{10}=0.17$ ); Task\*Foreperiod\*Cue-repetition ( $p=.46$ ,  $\eta^2_p=.01$ ,  $BF_{10}=0.09$ ); Task\*Spatial attention\*Foreperiod\*Cue-repetition ( $p=.88$ ,  $\eta^2_p<.01$ ,  $BF_{10}=0.09$ ).

Cite as:  
Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

When the cue consisted of 4 taps, there was a main effect of Foreperiod ( $F(2,114)=18.31$ ,  $p<.001$ ,  $\eta^2_p=.24$ ) and trend analysis showed this effect was linear ( $F(1,57)=28.48$ ,  $p<.001$ ,  $\eta^2_p=.34$ ) and not quadratic ( $p=.060$ ,  $\eta^2_p=.06$ ). Analysis of five stimulus-repetitions showed no effect of Foreperiod ( $p=.55$ ,  $\eta^2_p=.01$ ,  $BF_{10}=0.04$ ) (see Figure 3, bottom).

Importantly there was no Spatial attention\*Foreperiod interaction ( $p=.58$ ,  $\eta^2_p=.01$ ,  $BF_{10}= 0.03$ ) or other interactions with Spatial attention or Foreperiod<sup>3</sup>. Specifically, the Spatial attention\*Foreperiod interaction showed a value of  $BF_{10}= 0.034$  which is less than 1/3 indicating the support for the null hypothesis. Put differently, the data are 29.5 time more likely under the two main effects model (Spatial attention and Foreperiod) than under a model that adds the interaction (Spatial attention\*Foreperiod).



**Figure 3.** Top Figure shows mean response times (RTs) in milliseconds (ms) for targets presented early, in synchrony or late in relation to the cue. RTs are averaged over task and stimulus-repetition. The effect of endogenous spatial attention is due to faster RTs for attended (white bars) compared to unattended targets

<sup>3</sup> Non-significant effects including Spatial attention or Foreperiod and not reported above: Spatial attention\*Cue-repetition ( $p=.616$ ,  $\eta^2_p<.01$ ,  $BF_{10}= 0.15$ ); Spatial attention\*Foreperiod\*Cue-repetition ( $p=.517$ ,  $\eta^2_p=.01$ ,  $BF_{10}= 0.07$ ).

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

(black bars). *Bottom*: Mean RTs for targets presented early, in synchrony or late in relation to the cue, averaged across Spatial attention. White patterned bars represent targets presented after the cue consisted of four taps. Solid grey bars show RTs for targets presented after five taps. The line represents the significant linear trend demonstrated for targets after four taps, consistent with a foreperiod effect with decreasing RTs following longer periods between two stimuli.

Taken together, there was a main effect of spatial attention with overall faster RTs for attended compared to unattended targets. This indicates participants followed instructions and the effect also replicates previous studies investigating endogenous spatial attention in touch (e.g., Jones & Forster, 2014; Lloyd et al., 1999). RTs were also faster for targets following five compared to four stimulus-repetitions. That is, overall more probable targets were faster compared to less certain targets. There was also an effect of foreperiod which was linear with faster RTs for longer compared to shorter foreperiods. This effect was only present when the target appeared after four and not five stimulus-repetitions (events 1-3 in Figure 2). There was no interaction between foreperiod effect and spatial attention. The foreperiod effect was the same regardless whether the target was spatially attended or unattended. There was a main effect of task with faster RTs for target detection than discrimination, but task did not interact with effects of temporal or spatial attention. The independent effect of spatial and temporal attention on RTs is consistent with studies using visual (Doherty et al., 2005; Weinbach, Shofty, Gabay, & Henik, 2015), auditory (Rimmele, Jolsvai, & Sussman, 2011), and audiovisual stimuli (Jones, 2015). This experiment shows that directing endogenous tactile attention to a spatial location is independent of the effects of exogenous temporal attention.

**Table 1.** Mean response times (in milliseconds) and standard deviations (in adjacent brackets), separately for the detection and discrimination tasks and conditions.

	Detection task				Discrimination task			
	Attended		Unattended		Attended		Unattended	
	<u>Four</u>	<u>Five</u>	<u>Four</u>	<u>Five</u>	<u>Four</u>	<u>Five</u>	<u>Four</u>	<u>Five</u>
<b>Early</b>	444 (185)	390 (175)	487 (201)	433 (191)	622 (191)	592 (189)	677 (219)	642 (205)
<b>In synchrony</b>	437 (185)	396 (181)	486 (207)	448 (194)	619 (193)	592 (188)	666 (212)	635 (200)
<b>Late</b>	421 (189)	3891 (186)	471 (218)	450 (204)	600 (189)	588 (182)	644 (212)	641 (193)

### 3. Experiment 2 - Exogenous spatial and exogenous temporal attention

### 3.1 Methods

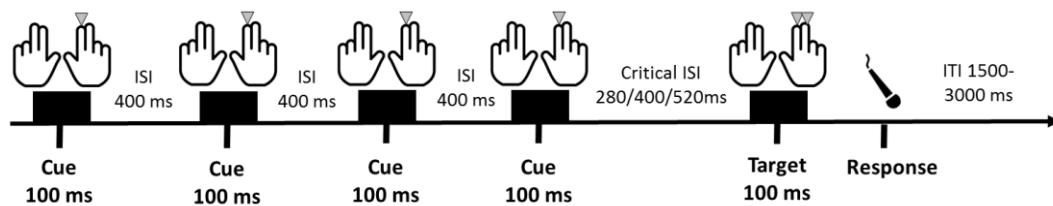
Methods were identical to experiment 1 with the following exceptions:

#### 3.1.1 Participants

Sixty participants took part in the study and 53 were included in the analysis (31 females and 22 males, average age 23.0 years; SD=3.0). Seven participants were excluded for not following instructions, responding to too many catch trials (>50%) or missing too many targets (>10%). All participants provided written informed consent.

#### 3.1.2 Design and Procedure

The design and procedure were identical to the detection task in experiment 1 with the following exceptions: The experiment consisted of 280 trials in five blocks, 56 trials per block. Overall there were 120 cued (the rhythmic cue and target appeared to the same hand) and 120 uncued trials (the cue appeared to the left hand and the target to the right hand, and vice versa). There were 40 catch trials where a cue was presented but no target. For each of the early, in synchrony and late conditions there were 80 trials, 40 when the cue consisted of four stimulus-repetitions and 40 when the cue included five stimulus-repetitions. The trials were presented in a random order. See Figure 4 for more details of events in a trial.



**Figure 4.** Schematic view of events in a trial in experiment 2. The cue was a 100 ms tap delivered to one hand only, either the index finger (indicated by the grey triangle) or middle finger. There were either four (as pictured above) or five unilateral taps in a trial. The inter-stimulus interval (ISI) between taps was 400 ms and therefore the stimulus onset asynchrony (SOA) was 500 ms, generating a 2 Hz rhythm. The target was a 100 ms tap to both index and middle fingers of only one hand. The target was either presented early, in synchrony or late (critical ISI 280, 400 or 520 ms respectively) in relation to the rhythm. The target was a single 100 ms tap and the participants responded by saying 'pa' into a microphone as soon as they felt the target. The inter-trial interval (ITI) was random between 1500 to 3000 ms. The target could be presented to the same hand (cued, as pictured above) or opposite hand (uncued).



Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

#### *Data analysis*

A 2x2x3 repeated measures ANOVA was used with the factors Spatial attention (cued, uncued), Stimulus-repetition (4, 5 taps), and Foreperiod (early, in synchrony, and late).

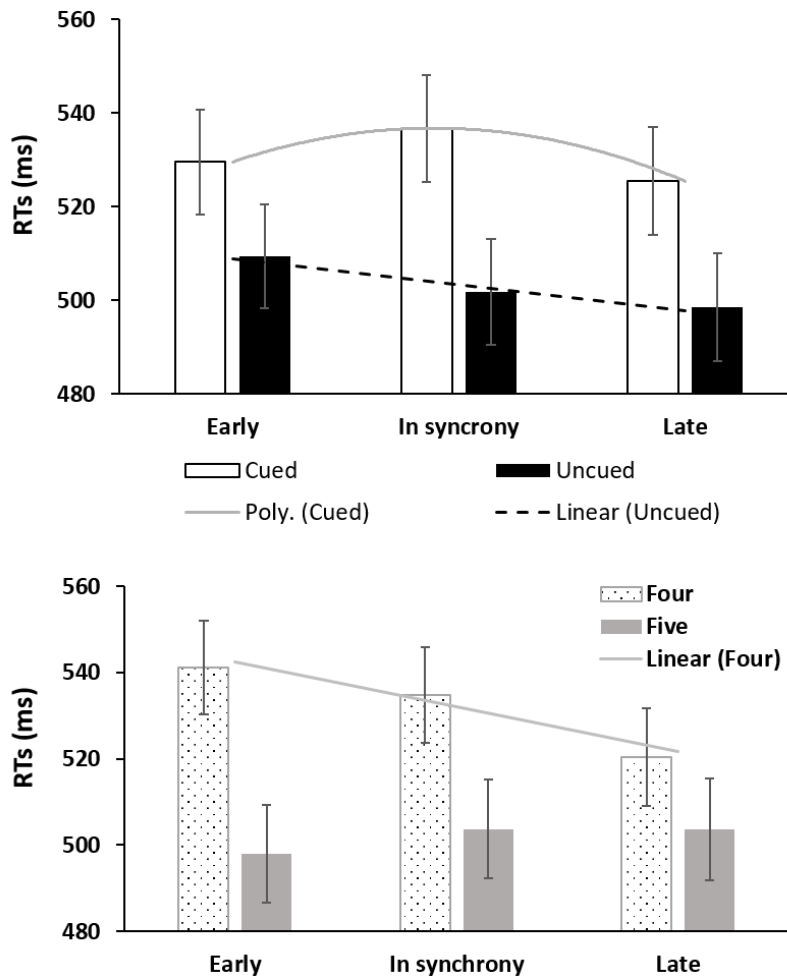
### **3.2 Results and discussion**

#### *Accuracy*

For the 53 participants, the average targets missed was 1.53% (SD=1.30%) and the average response to catch trials was 1.75% (SD=3.24%).

#### *Response times*

There was a main effect of Spatial attention ( $F(1,52)=107.93$ ,  $p<.001$ ,  $\eta^2_p=.66$ ) with faster RTs for uncued ( $M=503.32$  ms,  $SEM=22.64$ ) compared to cued targets ( $M=530.55$  ms,  $SEM=22.64$ ), in other words showing IOR (see Table 2 for a breakdown of RTs by condition). There was a main effect of Stimulus-repetition ( $F(1,52)=85.98$ ,  $p<.001$ ,  $\eta^2_p=.62$ ) with faster RTs for targets when the rhythmic cue consisted of five ( $M=501.77$  ms,  $SEM=22.98$ ) compared to four taps ( $M=532.10$  ms,  $SEM=22.22$ ). There was also a main effect of Foreperiod ( $F(1,7,87.5)=4.07$ ,  $p=.027$ ,  $\eta^2_p=.07$ ) and trend analysis showed a linear effect ( $F(1,52)=4.65$ ,  $p=.038$ ,  $\eta^2_p=.08$ ) and not quadratic ( $p=.09$ ,  $\eta^2_p=.05$ ). There was a Spatial attention\*Stimulus-repetition interaction ( $F(1,52)=4.02$ ,  $p=.05$ ,  $\eta^2_p=.07$ ) and a Foreperiod\*Stimulus-repetition interaction ( $F(2,104)=27.63$ ,  $p<.001$ ,  $\eta^2_p=.35$ ). Interestingly there was a Spatial attention\*Foreperiod interaction ( $F(2,104)=8.49$ ,  $p<.001$ ,  $\eta^2_p=.14$ )(see Figure 5, top). There was no Spatial attention\*Foreperiod\*Stimulus-repetition interaction ( $p=.55$ ,  $\eta^2_p=.01$ ,  $BF_{10}=0.07$ )



**Figure 5.** *Top:* Response times (RTs) for cued (white) and uncued (black) targets separately for when targets were presented early, in synchrony or late in respect to the preceding rhythm. There was a main effect of inhibition of return (IOR) with slower responses for cued compared to uncued targets. Lines represent significant trend lines. When targets were cued there was a quadratic (Poly.) trend with slower responses for in synchrony compared to early and late targets. When targets were uncued, the effect was linear in line with the foreperiod effect. *Bottom:* White patterned bars represent targets presented after the cue consisted of four taps. Solid grey bars show RTs for targets presented after five taps. The line represents the significant linear trend demonstrated for targets after four taps.

The significant interactions including Spatial attention were followed up by separate analysis for cued and uncued targets.

#### *Cued targets*

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Analysis of cued targets showed a main effect of Foreperiod ( $F(2,104)=5.81$ ,  $p=.004$ ,  $\eta^2_p=.10$ ) and trend analysis showed that this effect was quadratic ( $F(1,52)=11.86$ ,  $p=.001$ ,  $\eta^2_p=.19$ ) and not linear ( $p=.19$ ,  $\eta^2_p=.03$ ) (see Figure 5 top, white bars and solid line). The quadratic effect was driven by slower RTs for in synchrony ( $M=536.66$  ms,  $SEM=22.39$ ) compared to early ( $M=529.56$  ms,  $SEM=22.39$ ) and late targets ( $M=525.44$  ms,  $SEM=23.30$ ). There was a main effect of Stimulus-repetition with ( $F(1,52)=77.78$ ,  $p<.001$ ,  $\eta^2_p=.60$ ) with faster RTs for cued targets preceded by five ( $M=513.84$  ms,  $SEM=22.50$ ) compared to four ( $M=547.26$  ms,  $SEM=23.24$ ) rhythmic taps.

**Table 2.** Response times (RTs) in milliseconds and standard deviations (SD) for targets presented early, in synchrony and late, separately for cued and uncued and after either four or five stimulus-repetitions. Inhibition of return (IOR) is Cued-Uncued RTs.

	Four stimulus-repetitions RTs (SD)			Five stimulus-repetitions RTs (SD)		
	<u>Cued</u>	<u>Uncued</u>	<u>IOR</u>	<u>Cued</u>	<u>Uncued</u>	<u>IOR</u>
<b>Early</b>	553 (161)	530 (159)	23	506 (166)	489 (165)	17
<b>In synchrony</b>	553 (165)	517 (162)	36	520 (168)	487 (167)	33
<b>Late</b>	536 (165)	505 (166)	31	515 (173)	493 (172)	22

#### *Uncued targets*

Analysis of only uncued targets showed a main effect of Foreperiod ( $F(1.7,88.6)=9.30$ ,  $p<.001$ ,  $\eta^2_p=.15$ ) and trend analysis showed this effect was linear ( $F(1,52)=13.26$ ,  $p=.001$ ,  $\eta^2_p=.20$ ) and not quadratic ( $p=.52$ ,  $\eta^2_p<.01$ ). The linear effect followed the foreperiod effect with faster RTs for a longer interval between the last tap in the rhythm and the target (509.50 ms>501.87 ms>498.59 ms for early>in synchrony>late targets respectively) (see Figure 5 top, black bars and dashed line). There was also a main effect of Stimulus-repetition ( $F(1,52)=58.00$ ,  $p<.001$ ,  $\eta^2_p=.53$ ) with overall faster RTs for targets preceded by five ( $M=489.67$  ms,  $SEM=23.35$ ) compared to four ( $M=517.33$  ms,  $SEM=22.35$ ) rhythmic taps.

Following the Stimulus-repetition\*Foreperiod interaction, four and five stimulus-repetitions were analysed separately.

#### *Four stimulus-repetitions*

There was a main effect of Spatial attention ( $F(1,52)=102.91$ ,  $p<.001$ ,  $\eta^2_p=.66$ ) with slower RTs for cued ( $M=547.26$  ms,  $SEM=22.34$ ) compared to uncued targets ( $M=516.95$  ms,  $SEM=22.19$ ). There

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

was also a main effect of Foreperiod ( $F(1.7,90.3)=20.17$ ,  $p<.001$ ,  $\eta^2_p=.28$ ) and trend analysis indicated the effect was linear ( $F(1,52)=29.53$ ,  $p<.001$ ,  $\eta^2_p=.36$ ) and not quadratic ( $p=.103$ ,  $\eta^2_p=.05$ ) (early:  $M=529.61$  ms,  $SEM=21.77$  / in synchrony:  $M=516.65$  ms,  $SEM=23.30$  / late:  $M=504.58$  ms,  $SEM=22.77$ ).

#### *Five stimulus-repetitions*

There was a main effect of Spatial attention ( $F(1,52)=61.08$ ,  $p<.001$ ,  $\eta^2_p=.54$ ) with slower RTs for cued ( $M=513.84$  ms,  $SEM=23.09$ ) compared to uncued targets ( $M=489.69$  ms,  $SEM=22.97$ ) whilst there was no main effect of Foreperiod ( $p=.18$ ,  $\eta^2_p=.03$ ,  $BF_{10}=0.16$ ).

Taken together results from experiment 2 showed an effect of spatial attention in the form of IOR with slower responses for cued compared to uncued targets. This shows IOR can be elicited using rhythmic cues. There was also a spatial attention and foreperiod interaction. The main interpretation of this interaction is that responses to spatially cued and uncued targets are differently sensitive to the rhythm-generated temporal attention effects. When the targets were uncued, the pattern follows a linear foreperiod effect with faster RTs for longer foreperiods. When the target appeared at the cued hand, the RT pattern was driven by the rhythmic cue. That is, a quadratic trend showed slower RTs when the target was in synchrony compared to early or late.

#### **4. General Discussion**

Orienting attention to a location in space, whether in the visual scene or a location on our body, influences perception and performance of attended stimuli. Similarly, attention can be allocated to specific points in time. The rhythmic structure of events in our environment can automatically generate anticipations which in turn influence perception and performance of temporally attended events. The present study investigated how temporal attention interacts with orienting attention in space. Overall, the results of this study show that space and time do interact, but only when both types of attention are exogenous. When the task requires orienting of endogenous spatial attention, then effects of space and time are independent.

The first objective was to explore the effects of exogenous temporal attention in touch. This was manipulated by using a rhythmic temporal structure as well as the probability of when the target would occur based on the hazard function. Participants were presented with a rhythm and targets were presented in or out of synchrony with this rhythm. The first finding to note is a foreperiod effect with fastest RTs for late and slowest RTs for early targets. That is, the longer the interval

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

between the last cue stimulus and target, the faster the RT. This effect was present and similar in both experiment 1 and 2, but only when the target appeared after four and not five stimulus-repetitions (see Figure 3 and 5, bottom). The presence of a foreperiod effect has previously been reported for tactile targets (van Ede et al., 2011). However, based on the hazard function (see Figure 2) this foreperiod effect would also be expected after five stimulus-repetitions. Instead there is no RT effect (see Figure 3 and Figure 5, bottom). The observed RT pattern comparing four and five stimulus-repetitions (in both experiments 1 and 2) are similar to what would be observed when contrasting variable to fixed foreperiods (Coull et al., 2016). That is, a foreperiod effect when the interval is variable and a flat pattern when the interval is fixed. Following five stimulus-repetitions, RTs for early, in synchrony and late targets are all equally fast, and moreover, they are all faster than RTs in response to targets after four stimulus-repetitions. There are several possible explanations which may be the reason for the observed pattern of results.

The first to consider is the impact of the rhythm in the tasks. There is some evidence to suggest the foreperiod effect is sensitive to the rhythmic context in a task. For example, Ellis and Jones (2010) observed a foreperiod effect when presenting sequences of tones with random time intervals. However, when tones were presented rhythmically the foreperiod effect disappeared. They concluded that the lack of foreperiod effect can be explained by the rhythm being entrained and this affects behaviour (RTs). It theoretically fits that the rhythm is “more” entrained after five compared to four stimulus-repetitions (see also McAuley and Fromboluti, 2014, for data supporting this). According to the DAT (Large & Jones, 1999), a different pattern would then be observed with faster RTs for in synchrony compared to early or late targets. However, both the DAT and foreperiod effect would predict slowest RTs for early targets, which was not the case in the five stimulus-repetition trials, in either experiment 1 or 2. In other words, the observed results do not seem to stem from the foreperiod effect and rhythmic entrainment (DAT) cancelling each other out. In fact, there is little direct support for the DAT in the present study across tasks. RTs did not show a U-shaped pattern benefitting in synchrony targets. Although this contradicts previous rhythmic cueing studies using RTs (e.g., Martin et al., 2005; Sanabria, Capizzi, Correa, 2011) and accuracy (Herrmann et al., 2016; Lawrance et al., 2014; Rohenkohl et al., 2012), there are also studies which do not support the DAT and even reporting detrimental effects of performance when presenting stimuli in synchrony with a rhythm (Barnes and Johnston, 2010; Spaak et al., 2014; Hickok et al., 2015; Large & Jones, 1999, Experiment 1). For example, Barnes and Johnston (2010) observed that when the target could appear at several different positions in a trial, there was a U-shaped pattern with worse performance for targets in synchrony compared to out of synchrony with the rhythm (Experiment 1).

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

However, when the target always appeared at the same serial position in the rhythm, then there was not difference in accuracy between early, in synchrony or late targets (Experiment 3). Moreover, Bauer et al. (2015) showed, over a series of experiments, a failure to replicate the inverted U-shaped pattern in the original pitch judgment task by Jones et al. (2002). Although there is little argument that rhythmic stimuli can affect behaviour, specific tasks parameters may promote or attenuate effects in support of the DAT (see Bauer et al., 2015 for a critical discussion).

Although the rhythmic structure of the cue was not directly relevant to the task, it still contained information which the participant could potentially have explicitly or implicitly used as a strategy in target processing. The target always appeared (apart from catch trials) towards the end of the trial. Therefore, it cannot be ruled out that endogenous temporal attention was engaged at this time point (Correa, Lupianez, & Tudela, 2006; Coull, Frith, Büchel, & Nobre, 2000). Engaging endogenous attention more after five compared to four stimulus-repetitions could potentially explain why the foreperiod effect disappears after five stimulus-repetitions. A related explanation<sup>4</sup> is that at the start of the trial, both four and five stimulus-repetitions are equally likely. So, a good strategy would be that the participant initially expects the target to occur after four stimulus-repetitions and strong temporal expectations are built up. If the target is not presented after four stimulus-repetitions, the initial expectation is violated and participants have to re-orient their attention in time. This re-orientation comes with a cost and the temporal manipulation is lost.

Whereas there are variety of possible explanations for the lack of RT effect after five stimulus-repetitions (endogenous orienting, ceiling effects, temporal expectation or counting strategies) which are not mutually exclusive, further research would be necessary to endorse any of these with confidence.

The second objective was to investigate how endogenous and exogenous spatial attention affect exogenous temporal attention. Experiment 1 showed a main effect of endogenous spatial attention with faster RTs for attended over unattended targets. This shows that participants followed instructions and that a rhythmic cue can be used to direct tactile attention similar to what has previously been demonstrated using a single symbolic visual (e.g., Forster & Eimer, 2005; Haegens et al., 2011) or tactile cue (Jones & Forster, 2013; Jones & Forster, 2014). Interestingly, endogenous spatial attention did not interact with the effects of exogenous temporal attention. The foreperiod effect, was the same for both attended and unattended targets. This independence is in line with

---

<sup>4</sup> Thanks to an anonymous reviewer.

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

rhythmic cueing studies using visual (Doherty et al., 2005), auditory (Jones, 2015) and crossmodal audiovisual stimuli (Jones, 2015), and now the tactile modality can be added to the list. Moreover, parallels can also be drawn to a study where participants were cued to expect either a visual or tactile target at a specific time point. Mühlberg, Oriolo, and Soto-Faraco (2014) showed that attending to one modality did not benefit the second, unattended modality, at the expected time point. That is, endogenous temporal attention can be deployed relatively independently across modalities (c.f. Lange and Röder, 2006). The independence is similar to the present results where exogenous temporal attention is independent from endogenous spatial attention effects. In line with this, different neuroanatomical areas have been proposed to reflect endogenous temporal attention (left inferior and superior parietal cortex; Cotti, Rohenkohl, Stokes, Nobre, & Coull, 2011; Coull et al., 2016; Davranche et al., 2011) and the hazard function (intraparietal sulcus and frontal cortex; Coull et al., 2016). However, it should be noted that interactions between rhythmic stimuli and endogenous spatial attention have been shown when the measure is performance accuracy (Kizuk & Mathewson, 2017) or components of perceptual processing (Doherty et al., 2005) rather than RTs. In other words, the absence of an effect demonstrating entrainment of the rhythm, and support for the DAT in experiment 1, could be due to RTs and not accuracy being the outcome measure.

Experiment 2 did not explicitly engage endogenous attention, spatial or temporal, but the rhythmic cue was unilateral and did not indicate where the target was likely to appear. Overall RTs were slower when cue and target were presented at the cued compared to uncued hand, demonstrating IOR (Klein, 2000). This replicates what has previously been observed in touch (e.g., Jones & Forster, 2012; Lloyd et al., 1999; Poliakoff, Spence, O'Boyle, McGlone, & Cody, 2002) and the present study now also shows that IOR can be observed using a rhythmic cueing paradigm. Moreover, there was an interaction between rhythmic exogenous temporal attention and exogenous spatial attention (see Figure 5, top) (see also Gabay & Henik, 2010, for interactions between IOR and temporal expectancy using a single cue). When targets appeared at the same hand as the rhythm (cued trials) then RTs followed an inverted U-shaped pattern with slower responses for targets in synchrony compared out of synchrony. However, this effect was not the case for uncued targets which followed a linear pattern. That RTs to in synchrony targets are different from out of synchrony targets indicates an effect of the rhythmic structure of the trial. The DAT suggests rhythms entrain periodic fluctuations of attention (Jones, 2010; Large & Jones, 1999). What may, at first glance, contradict the DAT is that RTs were slower for in synchrony targets. The DAT and recent theories of entrainment of neural oscillations (see introduction) propose a benefit of presenting in synchrony compared to out of synchrony stimuli. In line with this we recently demonstrated a RT benefit for in

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

compared to out of synchrony auditory targets following a tactile rhythm (Jones, Hsu, Granjon, & Waszak, 2017). Whereas one could concoct an explanation based on DAT by assuming that more attention (for in-synchrony targets, as entailed by DAT) results in more IOR (which is present only at the cued location), explaining the results this way should be done with caution as there is little overall evidence for the DAT in this study.

An alternative account of the difference between cued and uncued targets is that the rhythm generated some form of habituation (Thompson & Spencer, 1966; Groves and Thompson, 1970). That is, the effect is not due to periodic fluctuations of exogenous attention but instead, repetitive stimulation of the cued hand leads to habituation (see Dukewich, 2009 for an in depth discussion of IOR and habituation). However, the first (of nine) characteristic of habituation (Thompson & Spencer, 1966, p. 18) suggests that: "Given that a particular stimulus elicits a response, repeated applications of the stimulus result in decreased response (habituation). The decrease is usually a negative exponential function of the number of stimulus presentations". This would predict any effect of habituation to be stronger after five compared to four stimulus-repetition, whilst this does not appear to be the case in the present study (see also McAuley and Fromboluti, 2014 for a similar conclusion using perceived durations of oddballs and rhythms). Similarly, there is little evidence for habituation in experiment 1 which includes the same repetitive stimulation. Although experiment 1 involves bilateral stimulation, according to a habituation account, a similar U-shaped pattern for both attended and unattended targets should be observed, and it should be more pronounced after five compared to four stimulus-repetitions. Neither a habituation account nor the DAT fit the data particularly well. However, what remains clear is that the timing of rhythmic stimuli influenced behaviour in experiment 2 and this temporal effect interacted with inhibition of return.

## **5. Summary and conclusion**

This study investigated the effects rhythmic tactile stimuli on responses to targets and the influence of spatial attention. In both endogenous and exogenous tasks, there was a foreperiod effect. This foreperiod effect was only observed after four and not five stimulus-repetitions. The spatial attention effects replicated what has previously been observed in tactile attention studies with facilitation of attended targets in the endogenous task and IOR in the exogenous task. This study also shows that these spatial attention effects are observed when using a rhythmic cueing paradigm. The rhythmic cue did not demonstrate any effects of entraining temporal attention in the endogenous task. The observed RT pattern for early, in synchrony, and late targets, whether a foreperiod effect or no effect, was the same for spatially attended and unattended targets. This



Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

indicates that the foreperiod effect and endogenous spatial attention independently affect behaviour. However, in the exogenous task, the rhythmic cue influenced target responses. When the targets were presented to the same hand (cued) then there were slower responses for in synchrony compared to out of synchrony targets, possibly demonstrating more inhibition as a function of a rhythmic temporal structure. This effect was not present for uncued targets. This study shows a close link between exogenous attention across space and time and adds to the rapidly growing research concerning how the brain uses rhythms and elapsed time to automatically generate expectations about upcoming events.

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

### **Acknowledgements**

I would like to thank Josefin Werme and Emilie Fallang for assistance with data organisation and collection. Thanks also to Lucy Sheppard, Sevgi Gunes, Ugurcan Erdem, Akash Jain and Pracheen Gemawat for help with collecting data. Thanks also to Dr Ian Jones for helpful comments on drafts of this manuscript.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

## References

- Arnal, L. H., & Giraud, A. L. (2012). Cortical oscillations and sensory predictions. *Trends in Cognitive Sciences*, 16(7), 390–398. <https://doi.org/10.1016/j.tics.2012.05.003>
- Ball, F., Michels, L. E., Thiele, C., & Noesselt, T. (2018). The role of multisensory interplay in enabling temporal expectations. *Cognition*, 170, 130-146.
- Balota, D.A., Yap, M.J., Hutchison, K.A., Cortese, M.J., Kessler, B., Loftis, B., Neely, J.H., Nelson, D.L., Simpson, G.B. and Treiman, R. (2007). The English lexicon project. *Behavior research methods*, 39(3), 445-459.
- Bauer, A. K. R., Jaeger, M., Thorne, J. D., Bendixen, A., & Debener, S. (2015). The auditory dynamic attending theory revisited: A closer look at the pitch comparison task. *Brain Research*, 1626, 198-210.
- Barnes, R., & Johnston, H. (2010). The role of timing deviations and target position uncertainty on temporal attending in a serial auditory pitch discrimination task. *The Quarterly Journal of Experimental Psychology*, 63(2), 341-355.
- Berger, A., Henik, A., & Rafal, R. (2005). Competition Between Endogenous and Exogenous Orienting of Visual Attention. *Journal of Experimental Psychology: General*, 134(2), 207–221. <https://doi.org/10.1037/0096-3445.134.2.207>
- Breska, A., & Deouell, L. Y. (2014). Automatic bias of temporal expectations following temporally regular input independently of high-level temporal expectation. *Journal of cognitive neuroscience*, 26(7), 1555-1571.
- Brown, R. J., Danquah, A. N., Miles, E., Holmes, E., & Poliakoff, E. (2010). Attention to the body in nonclinical somatoform dissociation depends on emotional state. *Journal of psychosomatic research*, 69(3), 249-257.
- Buhusi, C. V., & Meck, W. H. (2005). What makes us tick? Functional and neural mechanisms of interval timing. *Nature Reviews Neuroscience*, 6(10), 755–765. <https://doi.org/10.1038/nrn1764>
- Busch, N. A., Dubois, J., & VanRullen, R. (2009). The phase of ongoing EEG oscillations predicts visual perception. *J Neurosci*, 29(24), 7869–7876. <https://doi.org/10.1523/JNEUROSCI.0113-09.2009>
- Calderone, D. J., Lakatos, P., Butler, P. D., & Castellanos, F. X. (2014). Entrainment of neural

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

oscillations as a modifiable substrate of attention. *Trends in Cognitive Sciences*, 18(6), 300–309.  
<https://doi.org/10.1016/j.tics.2014.02.005>

Carrasco, M. (2014). Spatial covert attention: perceptual modulation. In K. Nobre (Ed.), *The Oxford Handbook of Attention*. Oxford University Press.

Carrasco, M., & Yeshurun, Y. (1998). No Title. *Nature*, 396(6706), 72–75.  
<https://doi.org/10.1038/23936>

Chica, A. B., Martín-Arévalo, E., Botta, F., & Lupiáñez, J. (2014). The Spatial Orienting paradigm: how to design and interpret spatial attention experiments. *Neuroscience & Biobehavioral Reviews*, 40, 35-51.  
Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, 3(3), 215–229.  
<https://doi.org/10.1038/nrn755>

Correa, A., Lupiáñez, J., Madrid, E., & Tudela, P. (2006). Temporal attention enhances early visual processing: A review and new evidence from event-related potentials. *Brain Research*, 1076(1), 116–128. <https://doi.org/10.1016/j.brainres.2005.11.074>

Correa, A., Lupianez, J., & Tudela, P. (2006). The attentional mechanism of temporal orienting: Determinants and attributes. *Experimental Brain Research*, 169(1), 58–68.  
<https://doi.org/10.1007/s00221-005-0131-x>

Correa, A., Lupiáñez, J., & Tudela, P. (2005). Attentional preparation based on temporal expectancy modulates processing at the perceptual level. *Psychonomic Bulletin & Review*, 12(2), 328–34.  
<https://doi.org/10.3758/BF03196380>

Cotti, J., Rohenkohl, G., Stokes, M., Nobre, A. C., & Coull, J. T. (2011). Functionally dissociating temporal and motor components of response preparation in left intraparietal sulcus. *NeuroImage*, 54(2), 1221–1230. <https://doi.org/10.1016/j.neuroimage.2010.09.038>

Coull, J., Frith, C., Büchel, C., & Nobre, A. (2000). Orienting attention in time: behavioural and neuroanatomical distinction between exogenous and endogenous shifts. *Neuropsychologia*, 38(6), 808–819. [https://doi.org/10.1016/S0028-3932\(99\)00132-3](https://doi.org/10.1016/S0028-3932(99)00132-3)

Coull, J. T., Cotti, J., & Vidal, F. (2016). Differential roles for parietal and frontal cortices in fixed versus evolving temporal expectations: Dissociating prior from posterior temporal probabilities with fMRI. *NeuroImage*, 141, 40–51. <https://doi.org/10.1016/j.neuroimage.2016.07.036>

Cite as:

- Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.
- Coull, J. T., & Nobre, A. C. (1998). Where and when to pay attention: the neural systems for directing attention to spatial locations and to time intervals as revealed by both PET and fMRI. *Journal of Neuroscience*, 18(18), 7426–7435. [https://doi.org/0270-6474/98/187426-10\\$05.00/0](https://doi.org/0270-6474/98/187426-10$05.00/0)
- Davranche, K., Nazarian, B., Vidal, F., & Coull, J. (2011). Orienting Attention in Time Activates Left Intraparietal Sulcus for Both Perceptual and Motor Task Goals. *Journal of Cognitive Neuroscience*, 23(11), 3318–3330. [https://doi.org/10.1162/jocn\\_a\\_00030](https://doi.org/10.1162/jocn_a_00030)
- Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology*, 1–17. <https://doi.org/10.3389/fpsyg.2014.00781>
- Dockstader, C., Cheyne, D., & Tannock, R. (2010). Cortical dynamics of selective attention to somatosensory events. *NeuroImage*, 49(2), 1777–1785. <https://doi.org/10.1016/j.neuroimage.2009.09.035>
- Doherty, J. R., Rao, A., Mesulam, M. M., & Nobre, A. C. (2005). Synergistic Effect of Combined Temporal and Spatial Expectations on Visual Attention, 25(36), 8259–8266. <https://doi.org/10.1523/JNEUROSCI.1821-05.2005>
- Dukewich, K. R. (2009). Reconceptualizing inhibition of return as habituation of the orienting response. *Psychonomic Bulletin & Review*, 16(2), 238–251. <https://doi.org/10.3758/PBR.16.2.238>
- Ellis, R. J., & Jones, M. R. (2010). Rhythmic context modulates foreperiod effects. *Attention, Perception, & Psychophysics*, 72(8), 2274–2288. <https://doi.org/10.3758/BF03196701>
- Forster, B., & Eimer, M. (2005). Covert attention in touch: Behavioral and ERP evidence for costs and benefits. *Psychophysiology*, 42(2), 171–179. <https://doi.org/10.1111/j.1469-8986.2005.00268.x>
- Gabay, S., & Henik, A. (2008). The effects of expectancy on inhibition of return. *Cognition*, 106(3), 1478-1486.
- Giabbiconi, C. M., Dancer, C., Zopf, R., Gruber, T., & Müller, M. M. (2004). Selective spatial attention to left or right hand flutter sensation modulates the steady-state somatosensory evoked potential. *Cognitive Brain Research*, 20(1), 58–66. <https://doi.org/10.1016/j.cogbrainres.2004.01.004>
- Grahn, J. A., & Rowe, J. B. (2013). Finding and Feeling the Musical Beat: Striatal Dissociations between Detection and Prediction of Regularity. *Cerebral Cortex*, 23(4), 913–921.

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

<https://doi.org/10.1093/cercor/bhs083>

Griffin, I., Miniussi, C., & Nobre, A. (2001). Orienting attention in time. *Frontiers in Bioscience*, 6(1), D660–D671. <https://doi.org/10.2741/Griffin>

Groves, P. M., & Thompson, R. F. (1970). Habituation: a dual-process theory. *Psychological review*, 77(5), 419.

Haegens, S., & Golumbic, E. Z. (2018). Rhythmic facilitation of sensory processing: a critical review. *Neuroscience & Biobehavioral Reviews*, 86, 150-165 <https://doi.org/10.1016/j.neubiorev.2017.12.002>

Haegens, S., Handel, B. F., & Jensen, O. (2011). Top-Down Controlled Alpha Band Activity in Somatosensory Areas Determines Behavioral Performance in a Discrimination Task. *Journal of Neuroscience*, 31(14), 5197–5204. <https://doi.org/10.1523/JNEUROSCI.5199-10.2011>

Henry, M. J., & Obleser, J. (2012). Frequency modulation entrains slow neural oscillations and optimizes human listening behavior. *Proceedings of the National Academy of Sciences*, 109(49), 20095–20100. <https://doi.org/10.1073/pnas.1213390109>

Henry, M. J., & Herrmann, B. (2014). Low-frequency neural oscillations support dynamic attending in temporal context. *Timing & Time Perception*, 2(1), 62-86. Herrmann, B., Henry, M. J., Haegens, S., & Obleser, J. (2016). Temporal expectations and neural amplitude fluctuations in auditory cortex interactively influence perception. *NeuroImage*, 124, 487–497. <https://doi.org/10.1016/j.neuroimage.2015.09.019>

Hickok, G., Farahbod, H., & Saberi, K. (2015). The rhythm of perception: entrainment to acoustic rhythms induces subsequent perceptual oscillation. *Psychological science*, 26(7), 1006-1013.

Janssen, P., & Shadlen, M. N. (2005). A representation of the hazard rate of elapsed time in macaque area LIP. *Nat Neurosci*, 8(2), 234–241. <https://doi.org/10.1038/nn1386>

JASP Team (2018). JASP (Version 0.8.6)[Computer software].

Jones, A. (2018). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. Data archive url: <https://osf.io/v7xby/>

Jones, A. (2015). Independent effects of bottom-up temporal expectancy and top-down spatial attention. An audiovisual study using rhythmic cueing. *Frontiers in Integrative Neuroscience*, 8.

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

<https://doi.org/10.3389/fnint.2014.00096>

Jones, A., & Forster, B. (2012). Reflexive attention in touch: An investigation of event related potentials and behavioural responses. *Biological Psychology*, 89(2), 313–322. <https://doi.org/10.1016/j.biopsycho.2011.11.004>

Jones, A., & Forster, B. (2013). Independent effects of endogenous and exogenous attention in touch. *Somatosensory and Motor Research*, 30(4). <https://doi.org/10.3109/08990220.2013.779243>

Jones, A., & Forster, B. (2014). Neural correlates of endogenous attention, exogenous attention and inhibition of return in touch. *European Journal of Neuroscience*, 40(2). <https://doi.org/10.1111/ejn.12583>

Jones, A., Hsu, Y.-F., Granjon, L., & Waszak, F. (2017). Temporal expectancies driven by self- and externally generated rhythms. *NeuroImage*, 156. <https://doi.org/10.1016/j.neuroimage.2017.05.042>

Jones, M. (2010). Attending to sound patterns and the role of entrainment. In A. C. Nobre & J. Coull (Eds.), *Attention and time* (pp. 137–330). Oxford: Oxford University Press.

Jones, M. R., Moynihan, H., Mackenzie, N., & Puente, J. (2002). Temporal Aspects of Stimulus-Driven Attending in Dynamic Arrays. *Psychological Science*, 13(4), 313–319.

Karlin, L. (1959). Reaction time as a funktion of foreperiod duration and variability. *Journal of Experimental Psychology*, 58(2), 185–191. <https://doi.org/10.1037/h0049152>

Katus, T., & Müller, M. M. (2016). Working memory delay period activity marks a domain-unspecific attention mechanism. *Neuroimage*, 128, 149-157.

Kessler, B., Treiman, R., & Mullennix, J. (2002). Phonetic biases in voice key response time measurements. *Journal of Memory and Language*, 47(1), 145-171.

Kizuk, S. A. D., & Mathewson, K. E. (2017). Power and Phase of Alpha Oscillations Reveal an Interaction between Spatial and Temporal Visual Attention. *Journal of Cognitive Neuroscience*, 29(3), 480–494. [https://doi.org/10.1162/jocn\\_a\\_01058](https://doi.org/10.1162/jocn_a_01058)

Klein, R. M. (2000). Inhibition of return. *Trends Cogn Sci*, 4(4), 138–147. [https://doi.org/S1364-6613\(00\)01452-2](https://doi.org/S1364-6613(00)01452-2) [pii]

Klein, R. M., & Lawrence, M. A. (2012). On the modes and domains of attention. In M. I. Posner (Ed.),

Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

*Cognitive neuroscience of attention*, 2nd Ed, pp 11-28. New York, NY: Guilford Press.

Kornblum, S., Hasbroucq, T., & Osman, A. (1990). Dimensional overlap: cognitive basis for stimulus-response compatibility--a model and taxonomy. *Psychological review*, 97(2), 253.

Lakatos, P., Karmos, G., Mehta, A. D., Ulbert, I., & Schroeder, C. E. (2008). Entrainment of neuronal oscillations as a mechanism of attentional selection. *Science*, 320(5872), 110–3. <https://doi.org/10.1126/science.1154735>

Lange, K., & Röder, B. (2006). Orienting attention to points in time improves stimulus processing both within and across modalities. *Journal of Cognitive Neuroscience*, 18(5), 715-729.

Large, E. W., & Jones, M. R. (1999). The dynamics of attending: How people track time-varying events. *Psychological Review*, 106(1), 119–159. <https://doi.org/10.1037/0033-295X.106.1.119>

Lawrance, E. L. A., Harper, N. S., Cooke, J. E., & Schnupp, J. W. H. (2014). Temporal predictability enhances auditory detection. *The Journal of the Acoustical Society of America*, 135(6), EL357-EL363. <https://doi.org/10.1121/1.4879667>

Le Bigot, N., & Grosjean, M. (2016). Exogenous and endogenous shifts of attention in perihand space. *Psychological research*, 80(4), 677-684.

Lawrence, M. A., & Klein, R. M. (2013). Isolating exogenous and endogenous modes of temporal attention. *Journal of Experimental Psychology: General*, 142(2), 560.

Lloyd, D. M., Bolanowski JR, S. J., Howard, L., & McGlone, F. (1999). Mechanisms of attention in touch. *Somatosensory & Motor Research*, 16(1), 3–10. <https://doi.org/10.1080/08990229970609>

Lloyd, D. M., Azañón, E., & Poliakoff, E. (2010). Right hand presence modulates shifts of exogenous visuospatial attention in near perihand space. *Brain and Cognition*, 73(2), 102-109.

Luce, R. (1986). *Response times: Their role in inferring elementary mental organization* (8th ed.). Oxford University Press on Demand.

Mangun, G., & Hillyard, S. (1990). Allocation of visual attention to spatial locations: Tradeoff functions for event-related brain potentials and detection performance. *Perception & Psychophysics*, 47(6), 532–550. <https://doi.org/10.3758/BF03203106>

Martin, T., Egly, R., Houck, J. M., Bish, J. P., Barrera, B. D., Lee, D. C., & Tesche, C. D. (2005).



Cite as:

Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.

Chronometric evidence for entrained attention. *Perception & Psychophysics*, 67(1), 168–184.  
<https://doi.org/10.3758/BF03195020>

McAuley, J. D., & Fromboluti, E. K. (2014). Attentional entrainment and perceived event duration. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 369(1658), 20130401.

Mora-Cortes, A., Ridderinkhof, K. R., & Cohen, M. X. (2017). Evaluating the feasibility of the steady-state visual evoked potential (SSVEP) to study temporal attention. *Psychophysiology*.  
<https://doi.org/10.1111/psyp.13029>

Morillon, B., Hackett, T. A., Kajikawa, Y., & Schroeder, C. E. (2015). Predictive motor control of sensory dynamics in auditory active sensing. *Current Opinion in Neurobiology*, 31, 230–238.  
<https://doi.org/10.1016/j.conb.2014.12.005>

Mühlberg, S., Oriolo, G., & Soto - Faraco, S. (2014). Cross - modal decoupling in temporal attention. *European Journal of Neuroscience*, 39(12), 2089-2097.

Niemi, P., & Naatanen, R. (1981). Foreperiod and Simple Reaction Time. *Psychological Bulletin*, 89(1), 133–162. <https://doi.org/10.1037/0033-2909.89.1.133>

Ng, A. W., & Chan, A. H. (2012). Finger response times to visual, auditory and tactile modality stimuli. In *Proceedings of the international multiconference of engineers and computer scientists* (Vol. 2, pp. 1449-1454).

Nobre, A. C., Correa, A., & Coull, J. T. (2007). The hazards of time. *Current opinion in neurobiology*, 17(4), 465-470.

Nobre, A. C. , & Rohenkohl, G. (2014). *Time for the Fourth Dimension in Attention*. (A. C. (Kia) Nobre & S. Kastner, Eds.), *The Oxford handbook of* (Vol. 1). Oxford University Press.  
<https://doi.org/10.1093/oxfordhb/9780199675111.013.036>

Nobre, A. C., & van Ede, F. (2018). Anticipated moments: temporal structure in attention. *Nature Reviews Neuroscience*, 19(1), 34.

Noel, J. P., Pfeiffer, C., Blanke, O., & Serino, A. (2015). Peripersonal space as the space of the bodily self. *Cognition*, 144, 49-57.

Poliakoff, E., Spence, C., O'Boyle, D. J., McGlone, F. P., & Cody, F. W. J. (2002). Tactile inhibition of return: non-ocular response inhibition and mode of response. *Experimental Brain Research*,

Cite as:

- Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.  
146(1), 54–59. <https://doi.org/10.1007/s00221-002-1153-2>
- Pomper, U., Keil, J., Foxe, J. J., & Senkowski, D. (2015). Intersensory selective attention and temporal orienting operate in parallel and are instantiated in spatially distinct sensory and motor cortices. *Human Brain Mapping*, 3259(April), 3246–3259. <https://doi.org/10.1002/hbm.22845>
- Posner, M. A. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32(1), 3–25. <https://doi.org/10.1080/00335558008248231>
- Posner, M. I. (1978). *Chronometric explorations of mind*. Lawrence Erlbaum. Retrieved from <http://psycnet.apa.org/record/1980-02340-000>
- Rimmele, J., Jolsvai, H., & Sussman, E. (2011). Auditory Target Detection Is Affected by Implicit Temporal and Spatial Expectations. *Journal of Cognitive Neuroscience*, 23(5), 1136–1147. <https://doi.org/10.1162/jocn.2010.21437>
- Rohenkohl, G., Coull, J. T., & Nobre, A. C. (2011). Behavioural dissociation between exogenous and endogenous temporal orienting of attention. *PLoS ONE*, 6(1), 1–5. <https://doi.org/10.1371/journal.pone.0014620>
- Rohenkohl, G., Cravo, A. M., Wyart, V., & Nobre, A. C. (2012). Temporal Expectation Improves the Quality of Sensory Information. *Journal of Neuroscience*, 32(24), 8424–8428. <https://doi.org/10.1523/JNEUROSCI.0804-12.2012>
- Rohenkohl, G., & Nobre, a. C. (2011). Alpha Oscillations Related to Anticipatory Attention Follow Temporal Expectations. *Journal of Neuroscience*, 31(40), 14076–14084. <https://doi.org/10.1523/JNEUROSCI.3387-11.2011>
- Rohenkohl, G., Gould, I. C., Pessoa, J., & Nobre, A. C. (2014). Combining spatial and temporal expectations to improve visual perception. *Journal of vision*, 14(4), 8-8.
- Sambo, C. F., & Forster, B. (2011). Sustained Spatial Attention in Touch: Modality-Specific and Multimodal Mechanisms. *The Scientific World JOURNAL*, 11, 199–213. <https://doi.org/10.1100/tsw.2011.34>
- Sambo, C. F., Gillmeister, H., & Forster, B. (2009). Viewing the body modulates neural mechanisms underlying sustained spatial attention in touch. *EUROPEAN JOURNAL OF NEUROSCIENCE*, 30(1), 143–150. <https://doi.org/10.1111/j.1460-9568.2009.06791.x> <https://doi.org/10.1111/j.1460-9568.2009.06791.x>

Cite as:

- Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.
- Sanabria, D., Capizzi, M., & Correa, Á. (2011). Rhythms that speed you up. *Journal of Experimental Psychology: Human Perception and Performance*, 37(1), 236.
- Schubotz, R. I. (2007). Prediction of external events with our motor system: towards a new framework. *Trends in Cognitive Sciences*, 11(5), 211–218. <https://doi.org/10.1016/j.tics.2007.02.006>
- Spaak, E., de Lange, F. P., & Jensen, O. (2014). Local entrainment of alpha oscillations by visual stimuli causes cyclic modulation of perception. *Journal of Neuroscience*, 34(10), 3536-3544.
- Spence, C., & Gallace, A. (2007). Recent developments in the study of tactile attention. *Canadian Journal of Experimental Psychology*, 61(3), 196–207. <https://doi.org/10.1037/cjep2007021>
- Spence, C., Pavani, F., & Driver, J. (2000). Crossmodal links between vision and touch in covert endogenous spatial attention. *Journal of Experimental Psychology: Human Perception and Performance*, 26(4), 1298–1319. <https://doi.org/10.1037/0096-1523.26.4.1298>
- Tamè, L., & Holmes, N. P. (2016). Involvement of human primary somatosensory cortex in vibrotactile detection depends on task demand. *NeuroImage*, 138, 184-196.
- Thompson, R. F., & Spencer, W. A. (1966). Habituation: a model phenomenon for the study of neuronal substrates of behavior. *Psychological review*, 73(1), 16.
- Todd, N. P. M., & Lee, C. S. (2015). The sensory-motor theory of rhythm and beat induction 20 years on: a new synthesis and future perspectives. *Frontiers in Human Neuroscience*, 9, 444. <https://doi.org/10.3389/fnhum.2015.00444>
- van Ede, F., de Lange, F., Jensen, O., & Maris, E. (2011). Orienting attention to an upcoming tactile event involves a spatially and temporally specific modulation of sensorimotor alpha- and beta-band oscillations. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 31(6), 2016–2024. <https://doi.org/10.1523/JNEUROSCI.5630-10.2011>
- van Ede, F., Winner, T., & Maris, E. (2015). Touch automatically upregulates motor readiness in humans. *Journal of Neurophysiology*, 114(6), 3121–3130. <https://doi.org/10.1152/jn.00504.2015>
- VanRullen, R. (2016). Perceptual Cycles. *Trends in Cognitive Sciences*, 20(10), 723–735. <https://doi.org/10.1016/j.tics.2016.07.006>

- Cite as:
- Jones, A. (2019). Temporal expectancies and rhythmic cueing in touch: The influence of spatial attention. *Cognition*, 182, 140-150.
- Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., ... & Meerhoff, F. (2017). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, 1-19.
- Weinbach, N., Shofty, I., Gabay, S., & Henik, A. (2014). Endogenous temporal and spatial orienting: Evidence for two distinct attentional mechanisms. *Psychonomic Bulletin & Review*, (August 2015), 967–973. <https://doi.org/10.3758/s13423-014-0750-y>
- Zagha, E., Casale, A. E., Sachdev, R. N. S., McGinley, M. J., & McCormick, D. A. (2013). Motor Cortex Feedback Influences Sensory Processing by Modulating Network State. *Neuron*, 79(3), 567–578. <https://doi.org/10.1016/j.neuron.2013.06.008>
- Zanto, T. P., Pan, P., Liu, H., Bollinger, J., Nobre, A. C., & Gazzaley, A. (2011). Age-related changes in orienting attention in time. *J Neurosci*, 31(35), 12461–12470. <https://doi.org/10.1523/JNEUROSCI.1149-11.2011>

## Appendix A

**Table 1.** Target discrimination errors in the discrimination task (experiment 1). Errors (in per cent) include when participants responded they felt a double tap but the target was a single tap, and vice versa.

	Four cue-rep				Five cue-rep			
	Attended		Unattended		Attended		Unattended	
	Error %	SD	Error %	SD	Error %	SD	Error %	SD
<b>Early</b>	3.13	(3.61)	3.35	(5.51)	2.90	(2.49)	1.79	(3.34)
<b>In synchrony</b>	2.16	(2.04)	1.34	(6.46)	2.53	(3.12)	1.56	(4.31)
<b>Late</b>	2.08	(2.75)	3.57	(3.94)	2.23	(2.77)	2.68	(3.24)

Note: Standard deviation (SD) is shown in parenthesis.